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INTRODUCTION TO DIGITAL IMAGE PROCESSING(U) LETTERMAN
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Abstract cont.

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INTRODUCTION TO DIGITAL IMAGE PROCESSING

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DECEMBER 1984

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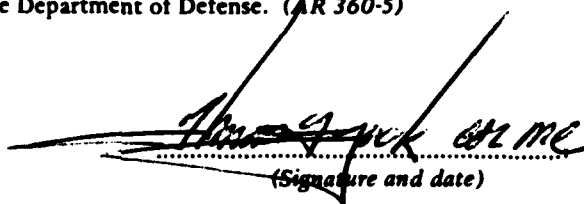
Introduction to digital image processing--Monroe and Zwick

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INTRODUCTION TO DIGITAL IMAGE PROCESSING

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This document

→ Digital image processing is the manipulation of the digital representation of an image. Source of the image can range from a common television video signal to complex imaging systems, such as a scanning electron microscope. Whatever the source of the image, the basic techniques for storing and manipulating data are common to many image processing applications. The actual hardware used in image processing is called a video frame grabber or frame buffer. Video frame grabbers costing under \$1000 are now available for many microcomputers including the IBM-PC, APPLE, and S-100 bus systems. Thus, image processing is available to users where previously costs were prohibitive. ~~We will~~ describe image storage, filtering techniques, and one possible application in the biological sciences.

*Image pixels; image techniques;
 Fourier filtering; resolution*

IMAGE STORAGE

The basic storage element of an image is a pixel (picture-element). A digitized image is arranged as an array of pixels with each pixel numerically coding the color, or shade of grey, of a unique location on the image. Typical sizes of these arrays are 256 x 256, 512 x 512, and 1024 x 1024 pixels. The larger the pixel array size, the higher the resolution (ability to show detail) of the image. Higher resolution requires increased memory and longer processing times. A doubling in resolution causes a quadrupling in storage space. The amount of computer memory used to store an individual pixel can range anywhere from 1-bit to 24-bits. Typically, black and white images will use between 1 to 8 bits/pixel and color images between 6 to 24 bits/pixel. More memory used per pixel, more colors or shades of grey are available for displaying the stored image. These storage requirements are similar to those in computer graphics applications. The only major difference between computer graphics and image processing is that the computer generates the entire pixel array for graphics, whereas in image processing the frame grabber brings the image into the computer by digitizing the video signal. Both tasks may be used simultaneously.

In this introductory paper we will manipulate black and white images stored in a 256 x 256 pixel array with 6-bits/pixel. Our baseline image (Fig 1) will be used to demonstrate the effects of several image processing routines.

This baseline image is the result of an ordinary scene being digitized by our system, which is typical of many of the inexpensive systems available on the market today. Even at 256 x 256 pixels/image edges in the scene are ragged. This is known as aliasing. By using software we reduce the resolution of the image to demonstrate how images from lower resolution frame grabbers might appear (Fig 2a, 2b). Even though these images appear coarse, like a mosaic, if one increases the viewing distance between himself and the image, he can still recognize the subject of the picture. Reducing the shades of grey in the image from our maximum of 64 down to 16, then 8 shades (Fig 3a, 3b) illustrate the need for quite a few bits of storage/pixel to avoid a cartoonish appearance of the image. Since each pixel in our image is stored in 6-bits, one pixel can have a numeric range of 0 to 63. By applying linear and non-linear transformation equations to these numeric values, contrast and brightness can be manipulated to correct or enhance shortcomings in the original image.

A powerful technique for enhancing images or extracting information from them is the use of digital filters to modify the individual pixel values. There are basically two methods for filtering an image. They are: using a convolution mask in the spatial domain, or using magnitude reduction of the Fourier components in the frequency domain. Before expanding upon the two methods for filtering images, we will interject some points on how it pertains to an image.

Since our image consists of 256 pixels across any given row, the highest spatial frequency we can have is 128 cycles/display, the result of alternating the shades of pixels between black and white. If we fill each row with the same black and white pattern, the screen will have 128 narrow black and white vertical bars (Fig 4a). We could also generate lower spatial frequencies by making several pixels black then making the next group of pixels white instead of alternating every other pixel (Fig 4b). If we make the entire row the same shade of grey, we would have a frequency of 0 cycles/display. Therefore, for our 256 x 256 pixel imaging system the spatial bandwidth is from 0 to 128 cycles/display. The spatial bandwidth is the same horizontally as vertically. A complex image, such as our baseline image, consists of many spatial components. Areas with rapidly changing contrast are high frequency, e.g. the edges on the buildings. Areas that do not have rapid changing contrast but a flat uniform appearance are low spatial frequencies, such as a street or side of a building. Digital filtering can be used selectively to enhance or remove these spatial components.

TWO METHODS OF DIGITAL FILTERING

Convolution - A simple and easy-to-use technique for enhancing images, extracting features, or reducing high frequency noise, is to convolute the image with a mask. The mask is simply an array of numbers arranged in such a way that when applied mathematically to the original image it will change the contrast, depending on the type of mask used. The actual convolution algorithm for a 3 x 3 mask is shown in Figure 5. The following three masks are used as examples of modifying an image by convolution (Fig 6a, b, c).

LOW Pass	HIGH Pass	EDGE Map
.1 .1 .1	-1 -1 -1	-1 -1 -1
.1 .2 .1	-1 9 -1	-1 8 -1
.1 .1 .1	-1 -1 -1	-1 -1 -1

Convoluting is the easy way to perform filtering but the masks are generally broadband, i.e. they cannot be designed just to remove or enhance a narrow spatial frequency range. To perform such finely tuned filtering Fourier analyses must be used.

With these mathematical procedures, complex waveforms in the time domain - or in the case of an image, spatial domain - can be reduced to a series of sine-waves in the frequency domain. Each of these sine-waves represents a different spatial component of the original waveform. The complex waveform in the spatial domain is a row or column of pixel data. The transformation of these pixel data for our particular system will produce spatial component information for frequencies ranging from 0 to 129 cycles. Sine-waves of varying amplitudes and phases, when added together, will reproduce the original image waveform. By selectively reducing the amplitude of sine-wave components, we can remove or reduce a given spatial frequency from the image. Using this technique, we can perform high-pass, low-pass, band-pass, and band-reject filtering of the image, removing or attenuating precisely the frequencies desired. An example of the power of this can be seen by taking an image and band-pass filtering it to extract only select spatial information (Fig 7). The nature of the Fourier transform is such that it is most useful when applied to images that have a high degree of periodicity. An example of this might be an image of cell patterns obtained from a microscope.

APPLICATIONS

The ability to extract spatial information from complex images is a non-trivial aspect of most scientific endeavors. In the biological sciences, spatial information is extremely important in defining complex and elusive structures of biological systems. Most microscopy techniques require staining to enhance contrast of the features within a specimen. Either in isolation or in combination, the ability to manipulate shades of grey or through digital imaging techniques has multiple applications.

Spatial filtering is still a relatively foreign technique to microscopy but its potential application as a method of extracting contour information, as well as elimination of spatial noise, should be easily recognized especially in those situations where the most subtle spatial aspect is sought. The ability to tune selectively to specific spatial regions, or tune out such regions, may be useful in microscopy where the experienced microscopist can combine his intuition with these powerful digital techniques. Spatial Fast Fourier Transforms have received considerable attention in the fields of vision and ophthalmology. Recent developments in the scientific understanding of how spatial vision is processed by the visual mechanisms suggest a strong affinity for neural mechanisms readily described with Fourier spatial analyses. Spatial channels are thought to underlie human spatial vision. The loss of such channels does not always mean a loss in fine spatial vision, usually known as visual acuity. Ocular disease can affect low frequency spatial channels leaving high spatial frequency channels intact. A person may show little loss in fine vision on typical tests of spatial vision but still have considerably altered vision.

Fourier filtering may help an ophthalmologist understand how fine vision may be unaffected, but complex shape vision can be seriously altered. It (filtering) provides us, as medical researchers, with the ability to construct complex stimuli degraded in a manner indicated by clinical dysfunction. Such stimuli can be used to train persons to utilize their remaining vision in a more efficient manner.

During the last five years, the microcomputer has become a dominant adjunct to our daily armamentarium. The techniques we have described represent a more sophisticated level of data analysis, analysis that could only be done with computer techniques. Until now, such techniques have been associated with the more expensive computer systems, with software not easily manipulated by other than an engineer. These impediments are being alleviated as digital image analysis hardware and software are becoming less expensive and simpler to use. With these more flexible spatial analysis tools, undoubtedly scientists can discover elusive underlying biological structures and find additional applications of these techniques.

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Figure 1. A 256 x 256 x 6 digitized image of the Bay Bridge of San Francisco. This is a raw image with no enhancing.



Figure 2. *A* (above), a 128 x 128 reduced resolution. *B* (below), a 64 x 64 reduced resolution.

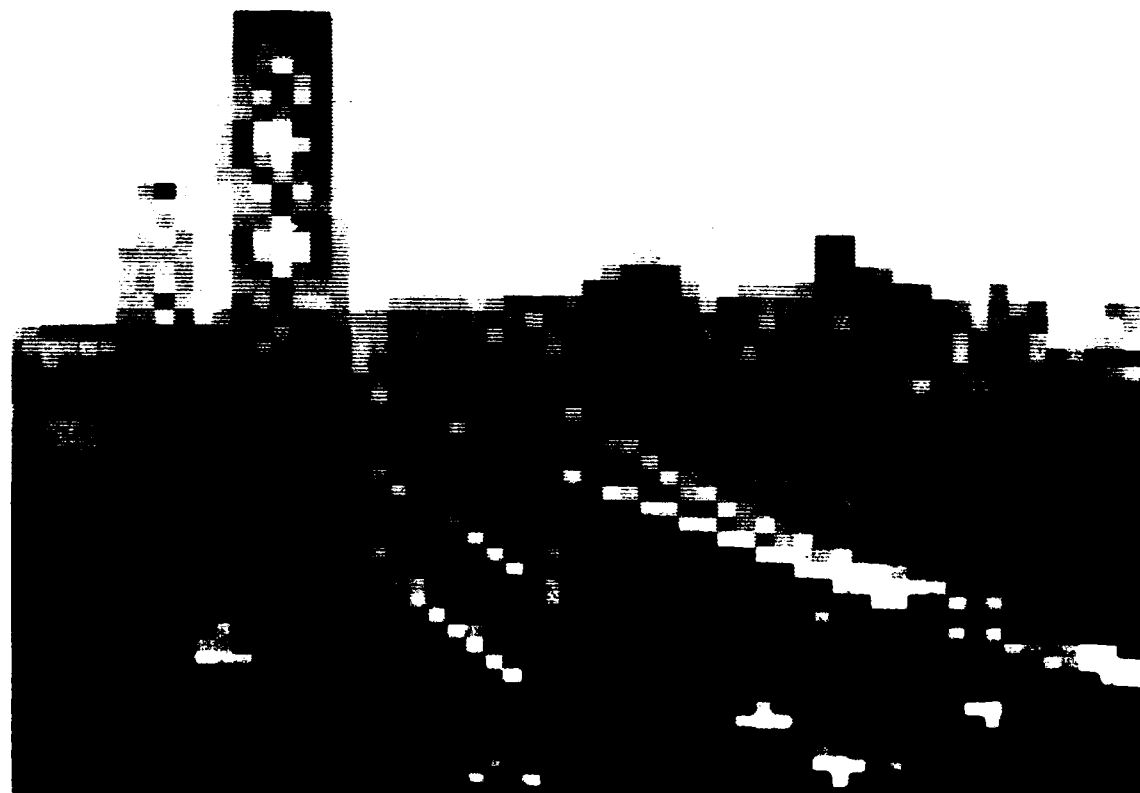




Figure 3. *A (above)*, with 16 shades of grey. *B (below)*, with 8 shades of grey.



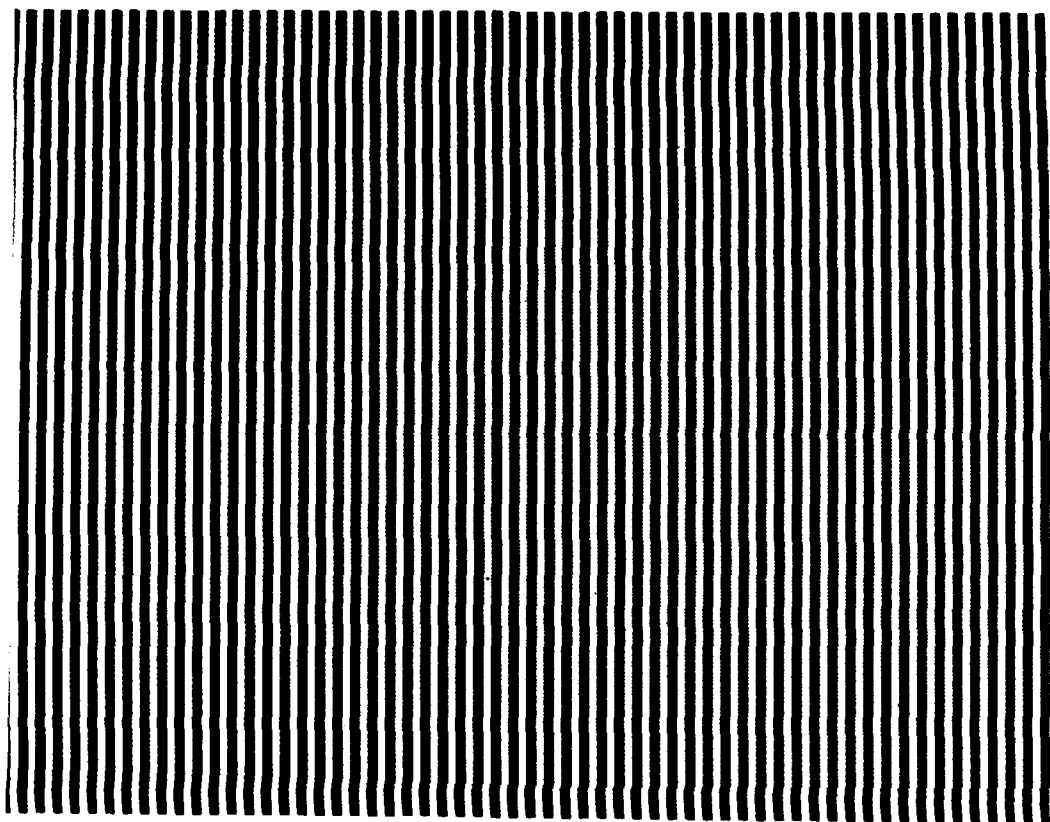
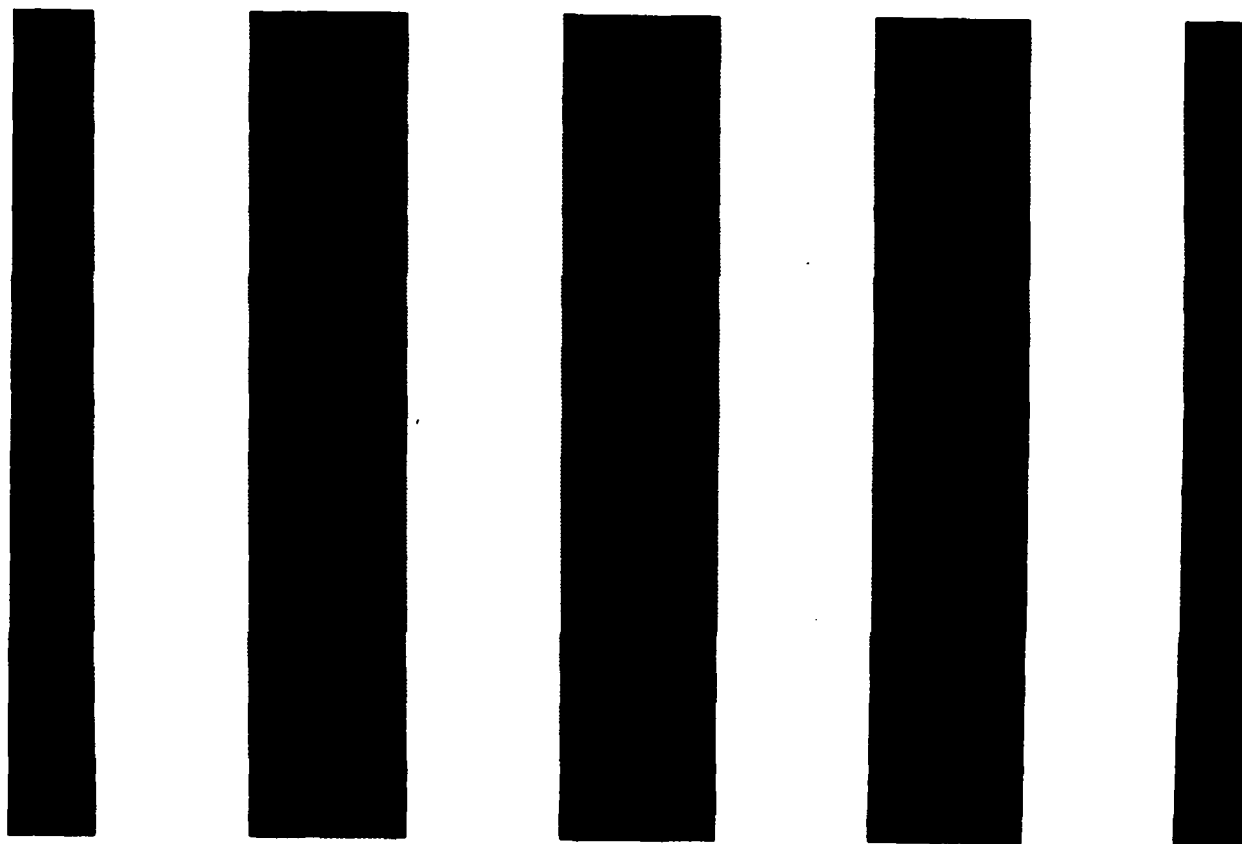


Figure 4. *A* (above), high frequency image. *B* (below), low frequency image.



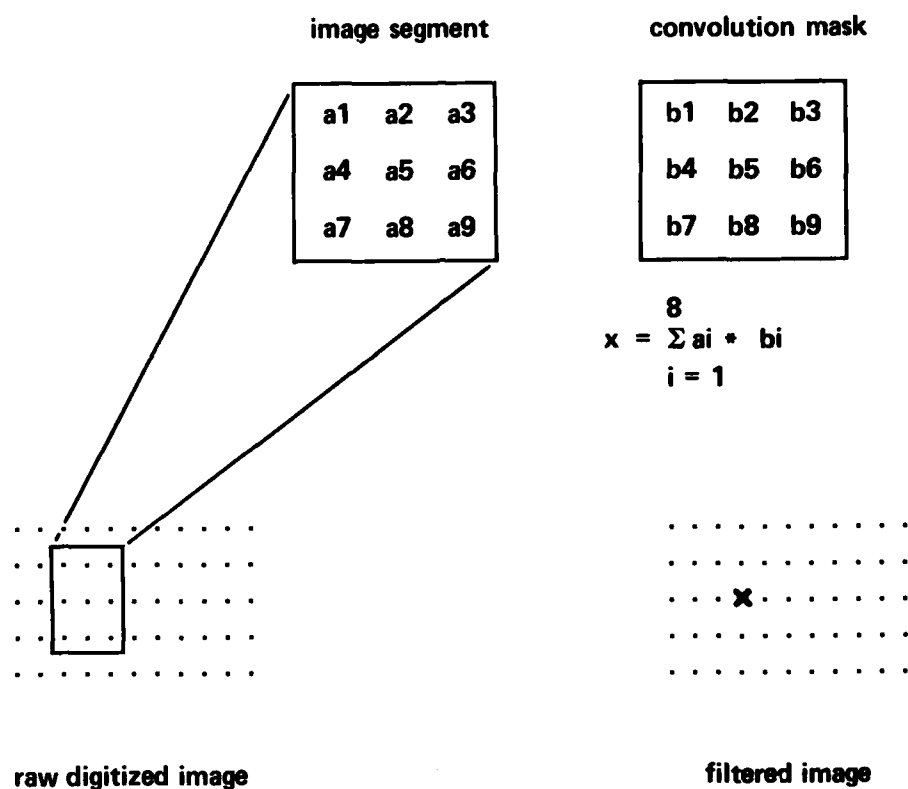


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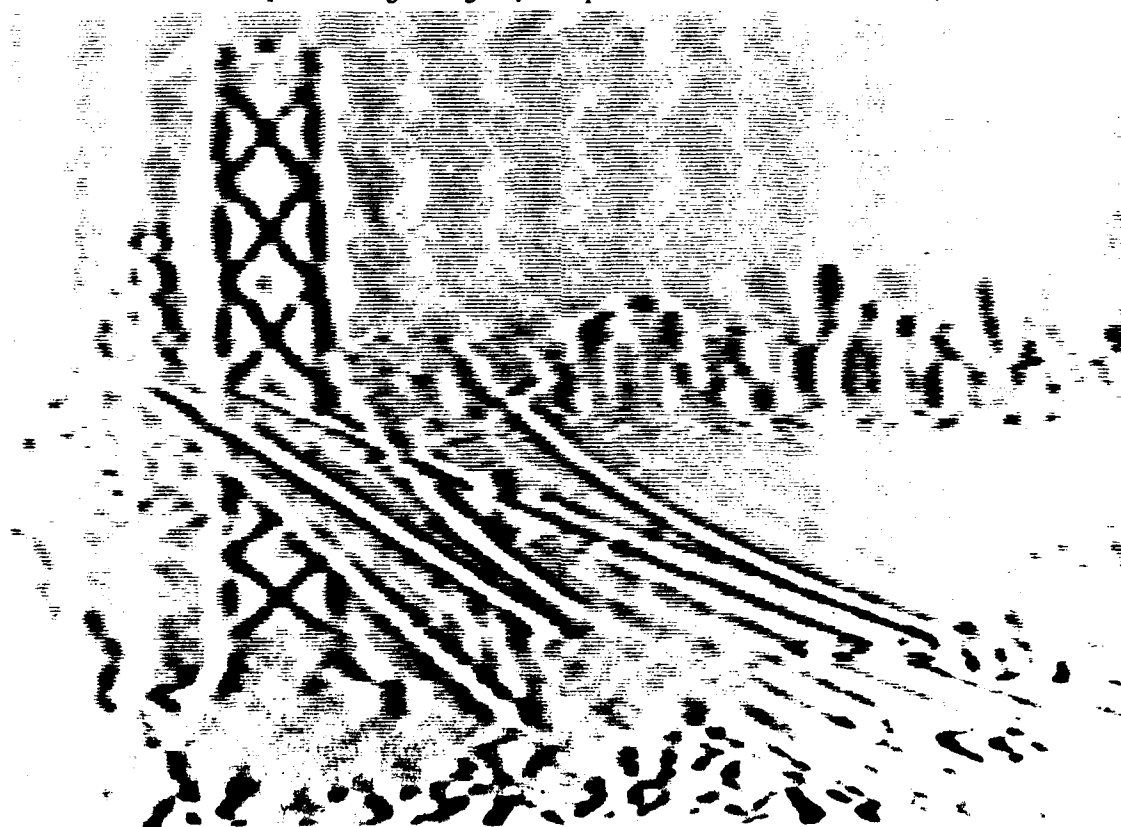
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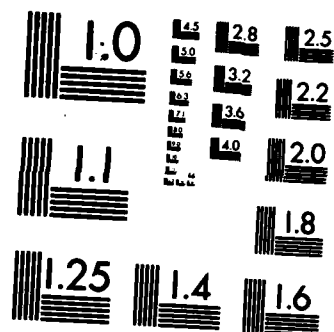
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SUPPLEMENTARY

INFORMATION

Errata

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Pages 6, 8, 10, 12, 14, 16 and 18
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